AIRS Calibration Update and Radiometric Uncertainty Estimate

Thomas S. Pagano[a]

Evan M. Manning[a], Steven E. Broberg[a] , Hartmut Aumann[a],

Margie Weiler[b], Kenneth Overoye[b]

[a]Jet Propulsion Laboratory, California Institute of Technology,

4800 Oak Grove Dr., Pasadena, CA 91109

tpagano@jpl.nasa.gov, (818) 393-3917, http://airs.jpl.nasa.gov

[b]BAE Systems, Nashua, New Hampshire, 03064 (Retired)

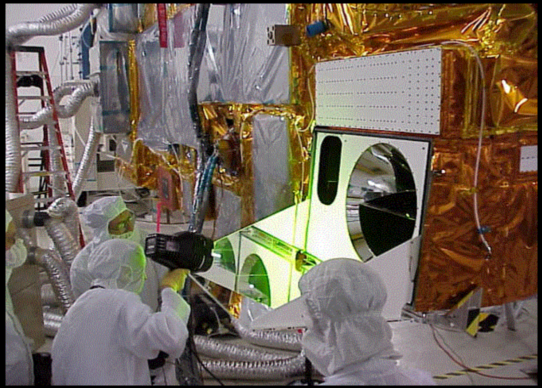
GSICS Annual Meeting 2019, Frascati, Italy

March 7, 2019

Agenda

- AIRS on Aqua Healthy. Expect mission to continue beyond 2022.
- Continuity from operational weather sounders: CrIS, IASI
- AIRS designed and tested to produce SI traceable radiances
- Radiometric Calibration Coefficients Updated
    - Current operational version using pre-launch coefficients (V5)
    - Updates provided to polarization, emissivity, nonlinearity (V7k)
- V7k Improvements seen in:
    - Reduced Bias and L/R Assymetry in Cold Scenes
    - Agrees better with CrIS
    - Reduction in Radiometric Accuracy

The Aqua Spacecraft
Launched May 4, 2002



Moderate Resolution Imaging Spectroradiometer (MODIS)
GSFC/Raytheon

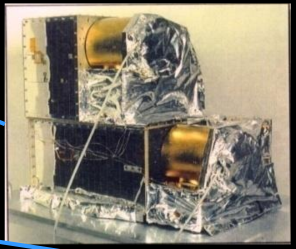
Atmospheric Infrared Sounder (AIRS)
JPL/BAE SYSTEMS

AQUA Spacecraft
GSFC/NGST

Advanced Microwave Scanning Radiometer (AMSR-E)
MSFC/JAXA

Advanced Microwave Sounding Units (AMSU-A/B)
JPL/Aerojet

Humidity Sounder from Brazil (HSB)
JPL/Aerojet

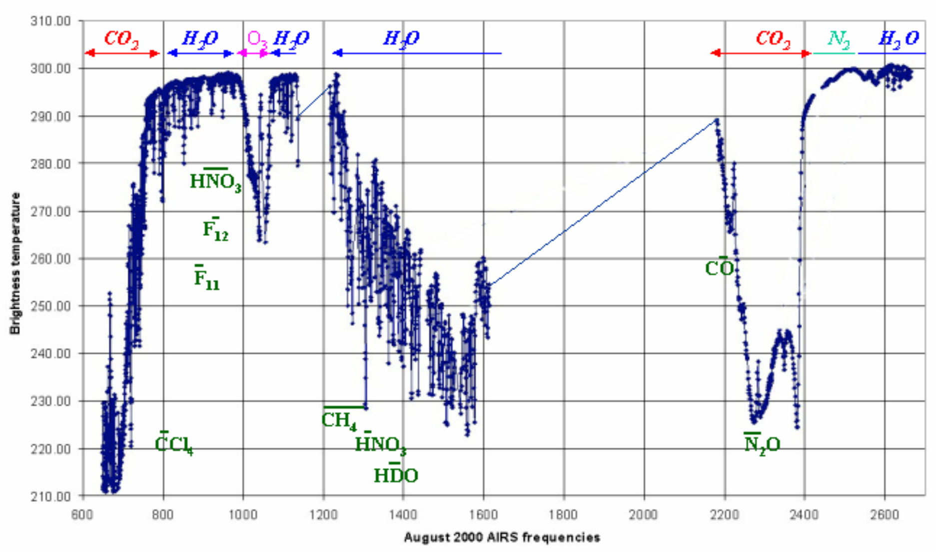


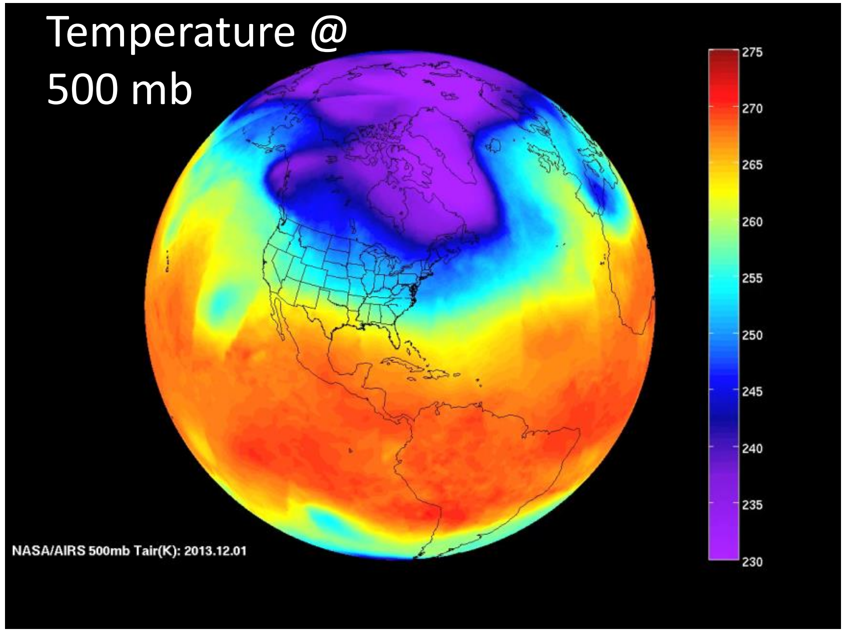
Clouds and Earth Radiant Energy System (CERES)
LaRC/NGST

IR Sounders Support Weather Forecasting and Climate Science

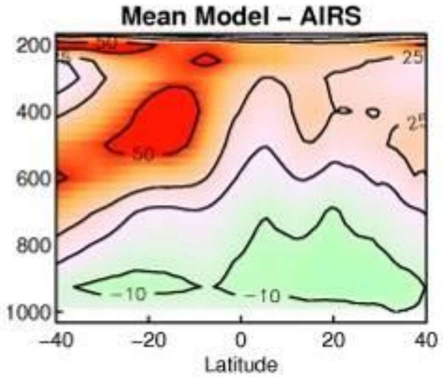
AIRS Channels for Tropical Atmosphere with T_surf = 301K

Full Spectrum





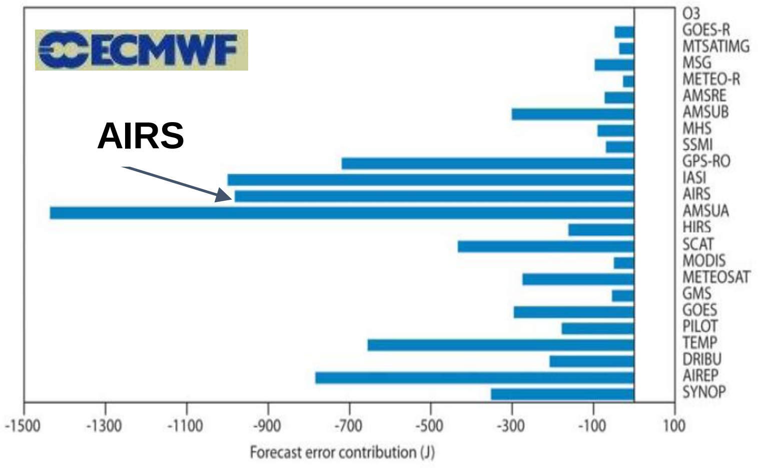
Water Vapor Climatology
(Pierce, Scripps, 2006)

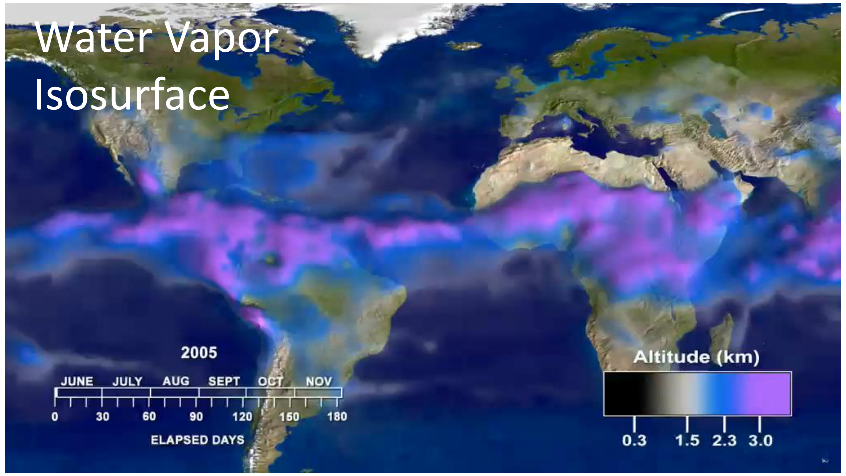


JPL/GSFC

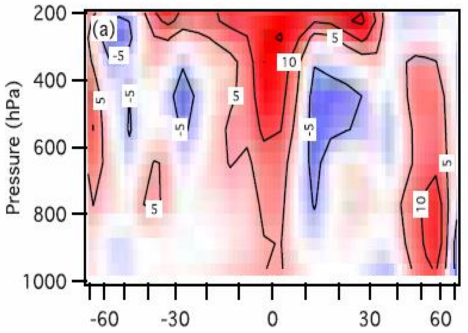
NOAA
NESDIS/NCEP

JCSDA



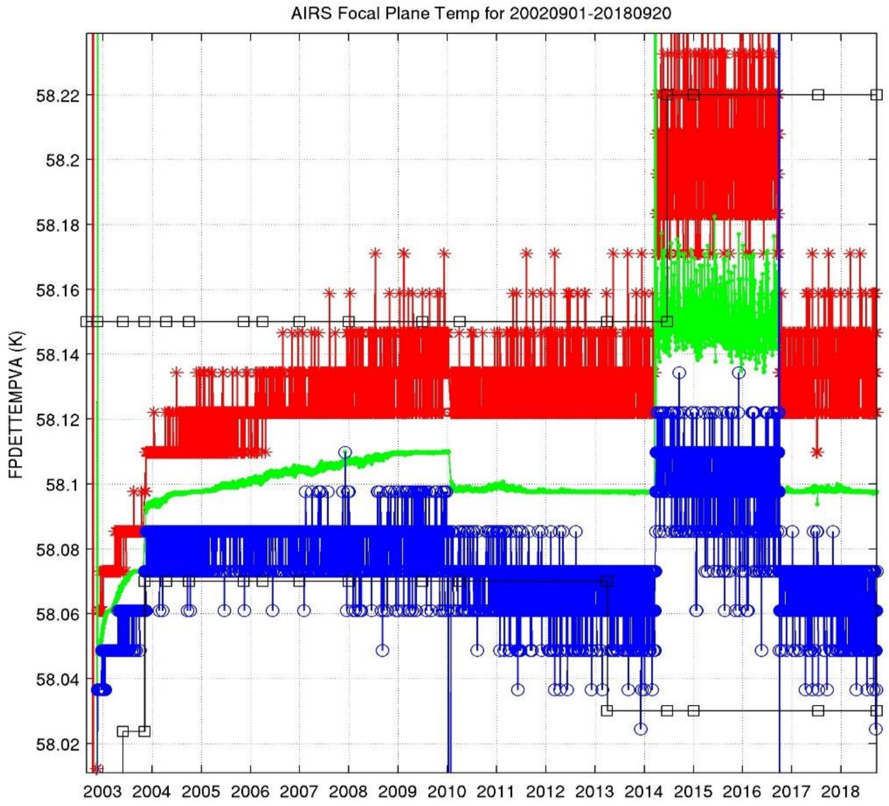


Water Vapor Feedback
(Dessler, Texas A&M, 2008)



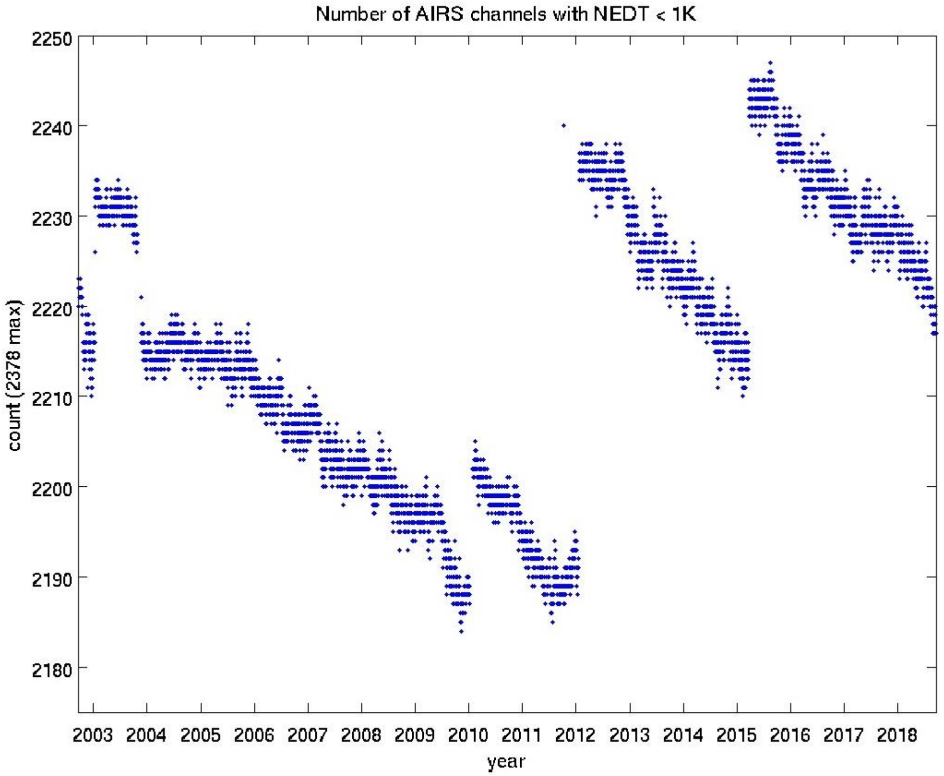
AIRS Remains Healthy

Minimal Trends in Instrument Telemetry



Focal Plane temperature has remained within a 0.25 K range throughout the AIRS mission. Note: Median temperature (green) rose ~0.06 K during 2014-2016 Cooler A anomaly

Detector Operability Maintained Throughout Mission

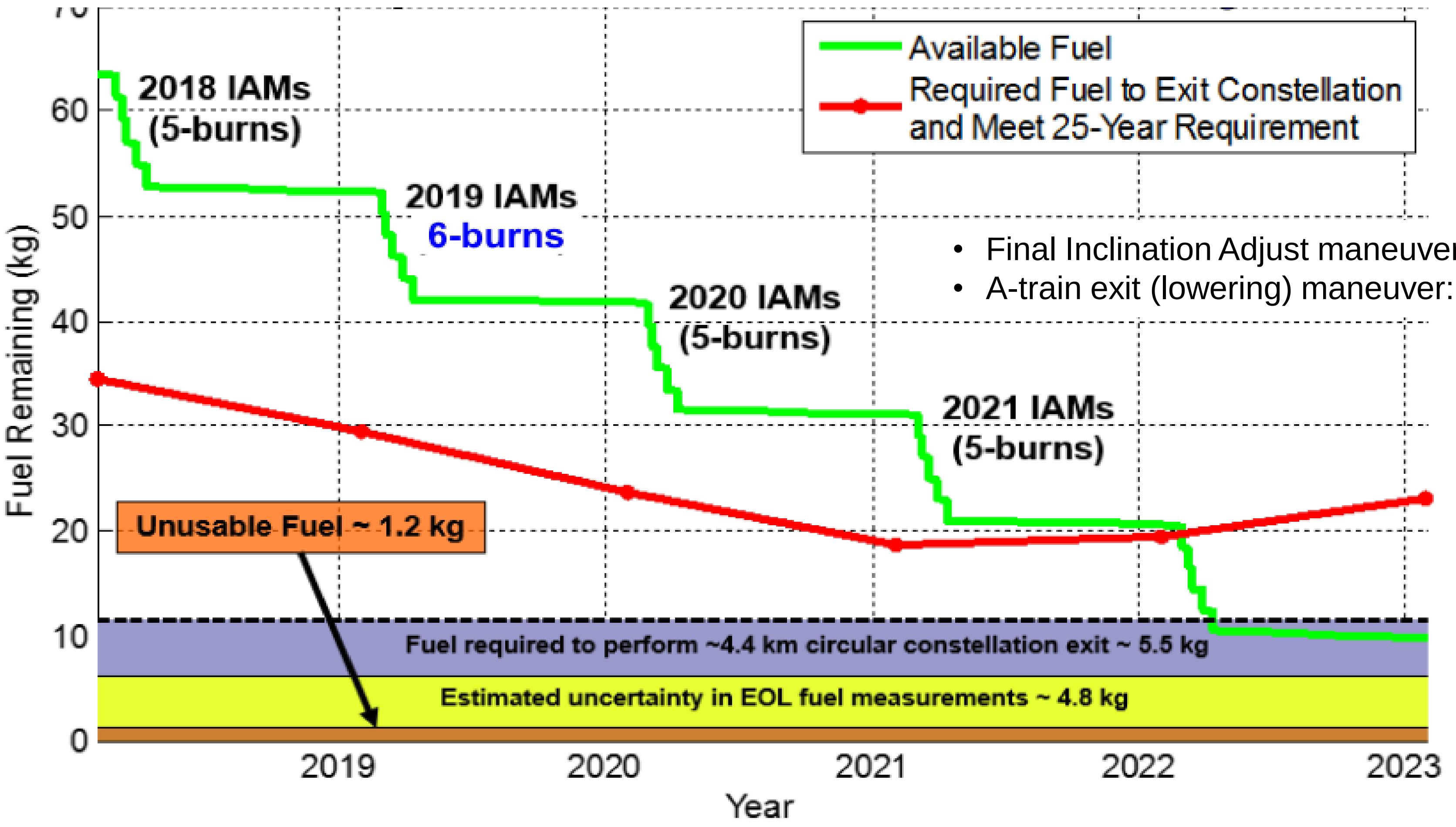


GainTable loads

2003-01-10	2013-06-10
2003-11-18	2015-03-23
2012-01-21	2018-xx-xx

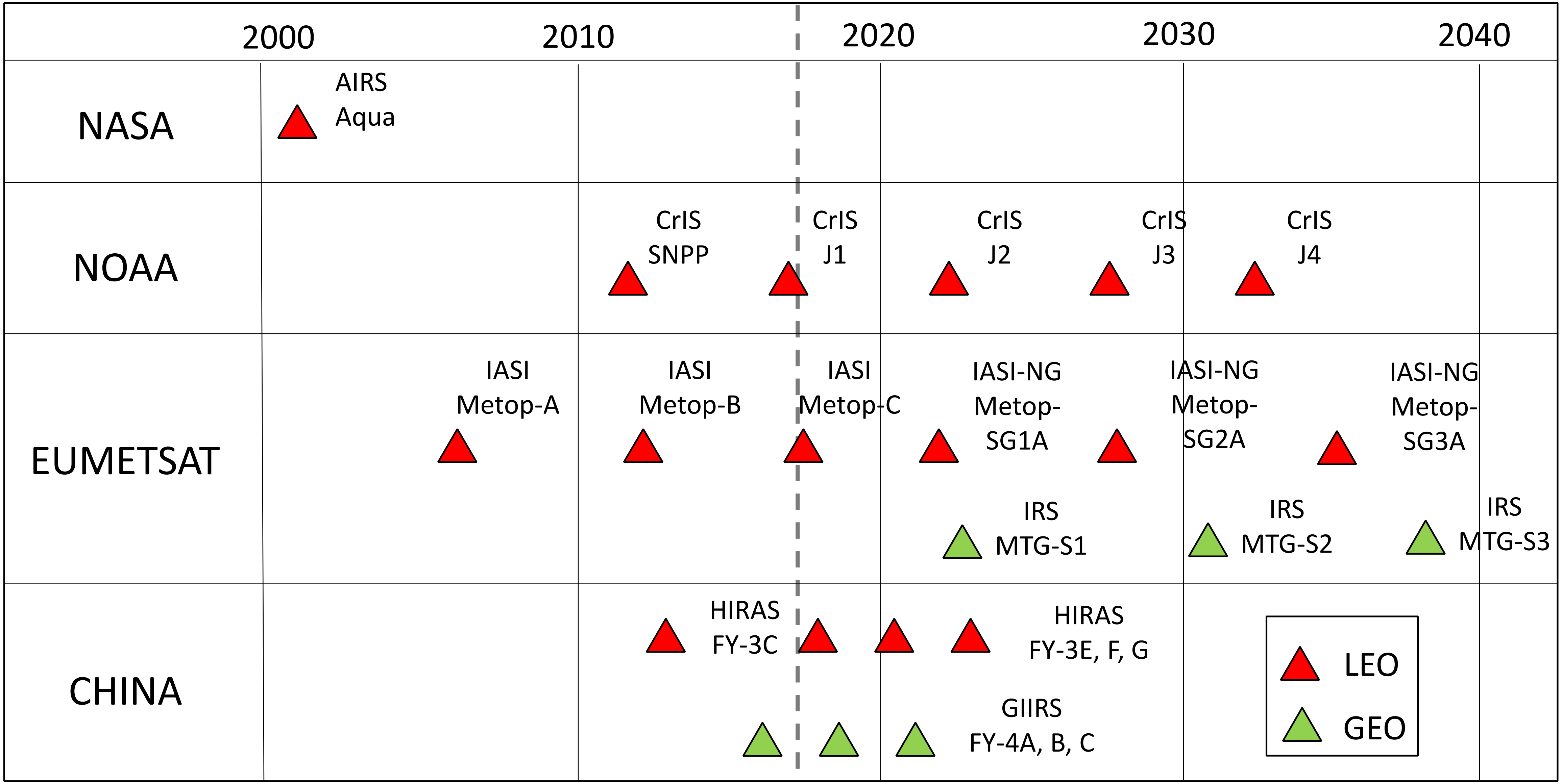
Aqua Expected to Last beyond 2022

- Aqua Flight Operations Team is continuing to test alternate orbit-lowering maneuver(s)
- Post-2022 orbit will also have thermal impact on AIRS – specifically, 2nd stage heater will need to draw more power to maintain spectrometer temperature
- AIRS is expected to last the life of the spacecraft



- Final Inclination Adjust maneuvers: March-April 2021
- A-train exit (lowering) maneuver: March 2022

AIRS Success Followed by Numerous Operational Sounders Worldwide



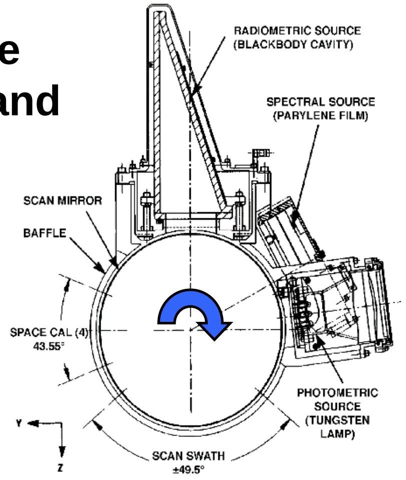
AIRS Demonstrates Key IR Sounding Technologies

AIRS Features

- Orbit: 705 km, 1:30pm, Sun Synch
- Pupil Imaging IFOV : 1.1° x 0.6°
  (13.5 km x 7.4 km)
- Scanner Rotates about Optical Axis
  (Constant AOI on Mirror)
- Full Aperture OBC Blackbody, ε>0.998
- Full Aperture Space View
- Solid State Grating Spectrometer
- Temperature Controlled
  Spectrometer: 158K
- Actively Cooled FPAs: 60K
- No. Channels: 2378 IR, 4 Vis/NIR
- Mass: 177Kg,
  Power: 256 Watts,
  Life: 5 years (7 years goal)

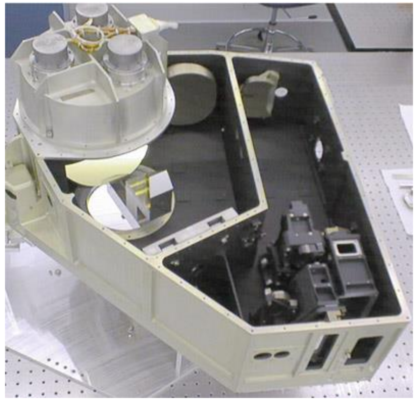
Full Aperture Blackbody and Space View

Isolated Scan Cavity



Temperature Controlled Instrument

Active Detector Cooling

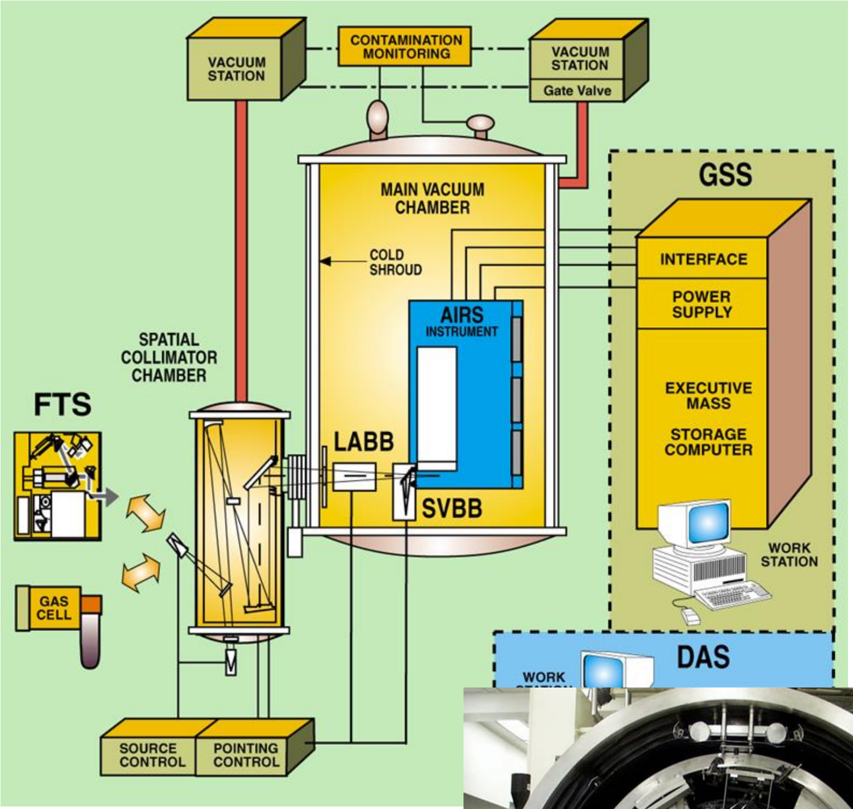


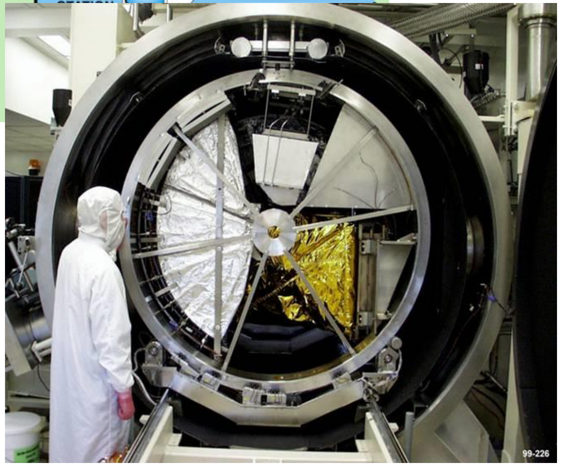
Grating Spectrometer

IR Spectral Range:
3.74-4.61 µm, 6.2-8.22 µm,
8.8-15.4 µm
IR Spectral Resolution:
≈ 1200 (λ/Δλ)
No. IR Channels: 2378 IR

Extensive Pre-flight Calibration on AIRS Ties to NIST Standards

- Radiometric Response
  - Emissivity, Nonlinearity
  - Stray Light, Polarization
  - Scan Angle Dependence in TVAC
  - Transfer to On-Board Blackbody
  - 2 TVAC Cycles
- Spectral Response
  - SRF Characterization with FTS
  - Channel Spectra Characterized
- Spatial Response
  - Top-hat Functions All Channels
  - Stray Light Excellent
  - Far Field Response Excellent
- Good Documentation
  - Over 400 Design File Memos





AIRS Radiometric Transfer Equations

Scene Radiance

$$L_{ev} = L_o(\theta) + \frac{c_0 + c_1'(dn_{ev} - dn_{sv}) + c_2(dn_{ev} - dn_{sv})^2}{[1 + p_r p_t cos2(\theta - \delta)]}$$

Mirror Polarization Contribution

$$L_o(\theta) = \frac{L_{sm} p_r p_t \left[cos2(\theta - \delta) - cos2\left(\theta_{sv,i} - \delta\right)\right]}{[1 + p_r p_t cos2(\theta - \delta)]}$$

Gain Term

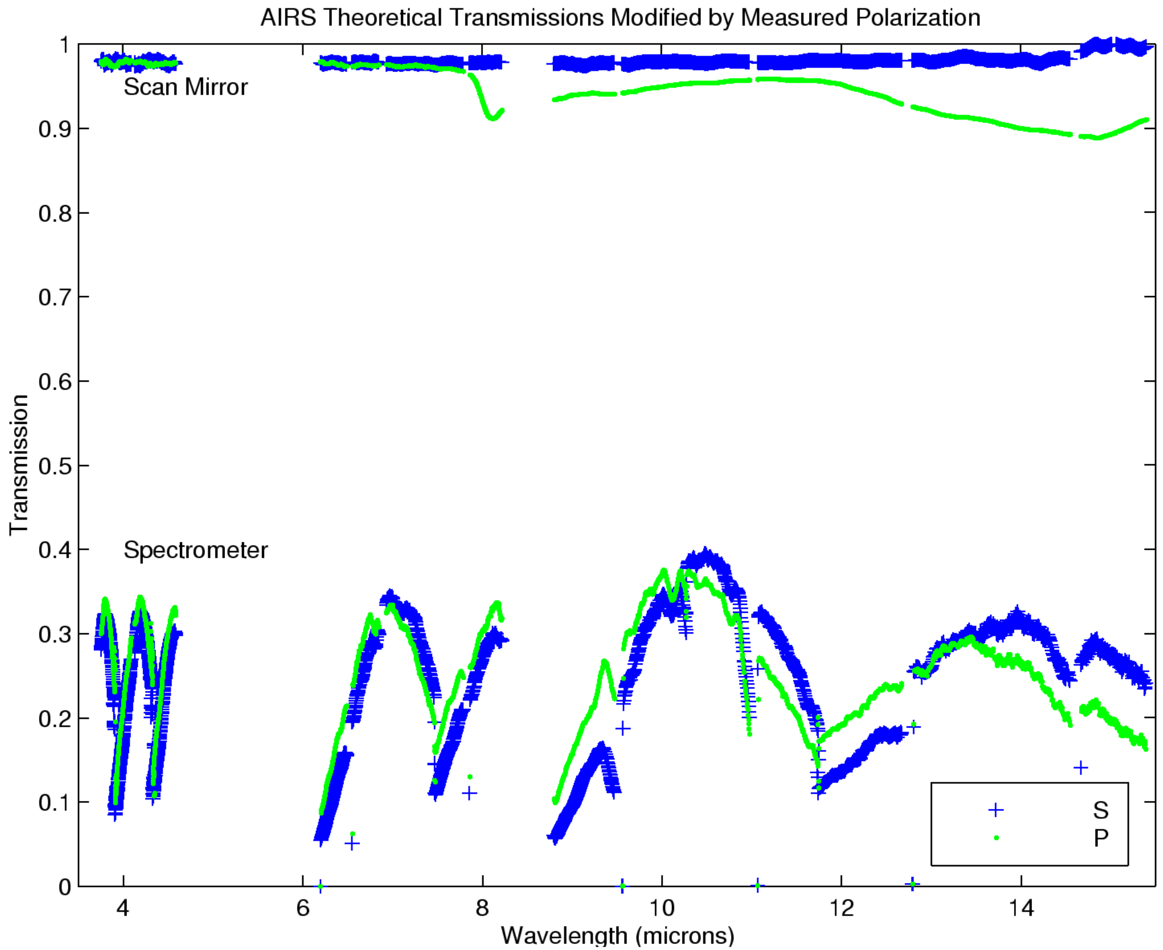
$$c_1{}' = \frac{[\varepsilon_{obc} P_{obc} - L_o(\theta_{obc})][1 + p_r p_t cos2\delta] - c_2(dn_{obc} - dn_{sv})^2 - c_0}{(dn_{obc} - dn_{sv})}$$

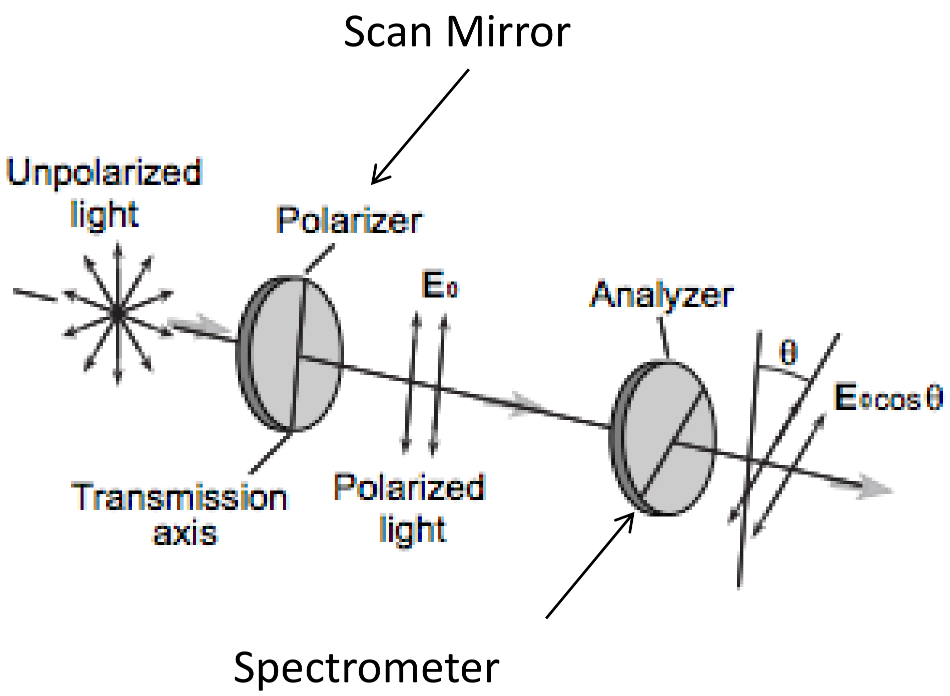
L_{ev} = Spectral Radiance in the Earth Viewport (W/m2-sr-μm)
L_{sm} = Spectral Radiance of the Scan Mirror for Unity Emissivity at T_{sm} (W/m^2-sr-μm)
c_0 = Instrument offset (W/m^2-sr- μm)
c_1 = Instrument gain (W/m^2-sr- μm-counts)
c_2 = Instrument nonlinearity (W/m^2-sr- μm-counts^2)
dn_{ev} = Digital counts while viewing Earth for each footprint and scan (counts)
dn_{sv} = Digital counts while viewing Space for each scan (counts)
$p_r p_t$ =Product of scan mirror and spectrometer polarization diattenuation (unitless)
θ = Scan Angle measured from nadir (radians)
δ = Phase of spectrometer polarization (radians)
P_{obc} = Plank Blackbody function of the OBC blackbody at temperature T_{obc} (W/m^2-sr-μm)
T_{obc} = Telemetered temperature of the OBC blackbody (K) with correction of +0.3K.
ε_{obc} = Effective Emissivity of the blackbody
dn_{obc} = Digital number signal from the AIRS while viewing the OBC Blackbody

V7k

- T. Pagano et al., “Reducing uncertainty in the AIRS radiometric calibration”, Proc. SPIE 10764-23, San Diego, CA (2018)
- T. Pagano et al., “Pre-Launch and In-flight Radiometric Calibration of the Atmospheric Infrared Sounder (AIRS),” IEEE TGRS, Volume 41, No. 2, February 2003, p. 265
- T. Pagano, H. Aumann, K. Overoye, “Level 1B Products from the Atmospheric Infrared Sounder (AIRS) on the EOS Aqua Spacecraft", Proc. ITOVS, October 2003

AIRS Scan Mirror and Spectrometer Act Like Polarizer and Analyzer





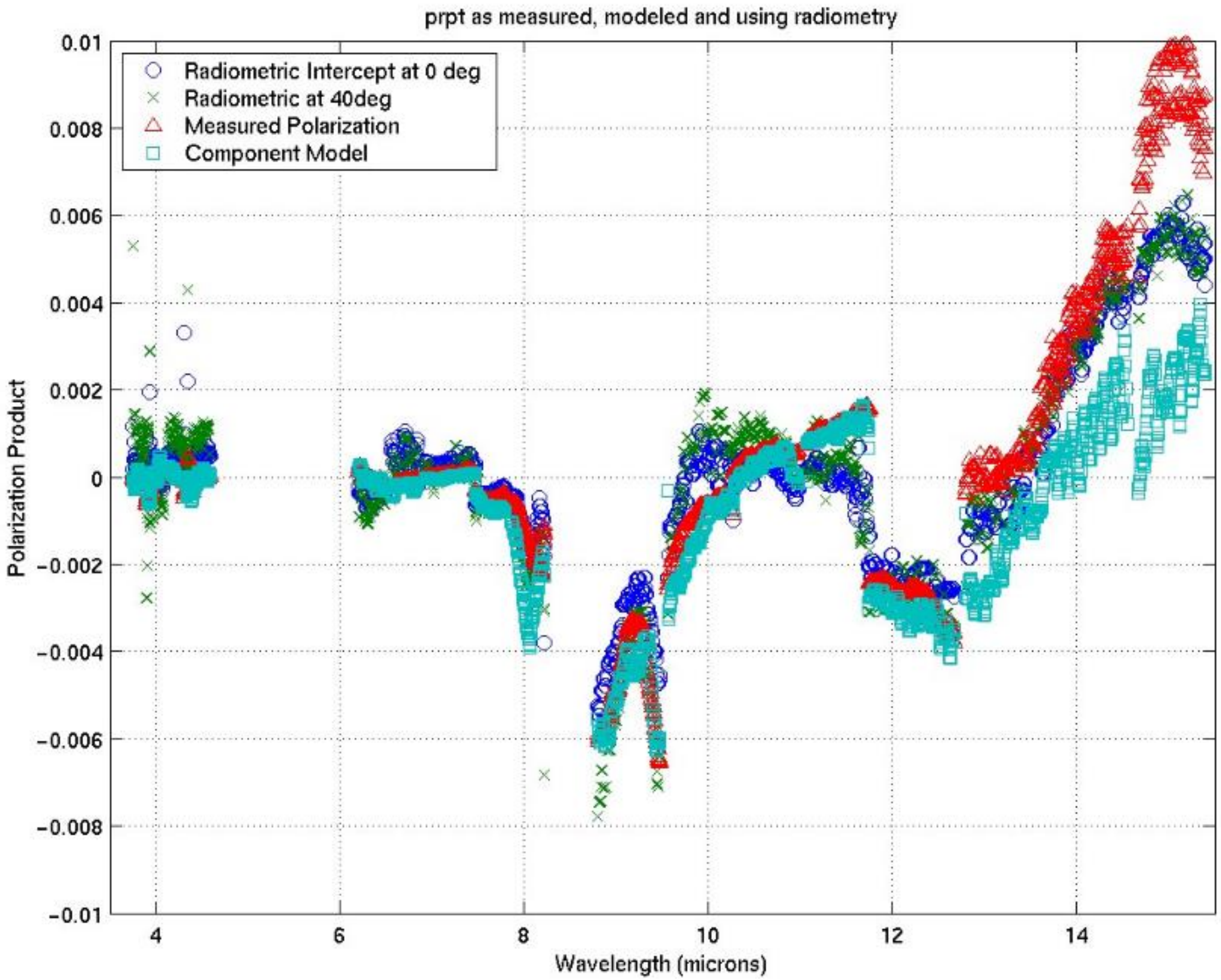
$$L_{ev} = L_o(\theta) + \frac{c_0 \;+\; c_1'(dn_{ev} - dn_{sv}) \;+\; c_2(dn_{ev} - dn_{sv})^2}{[1 + p_r p_t cos2(\theta - \delta)]}$$

Assumes all space views at 90°

$$L_o(\theta) = \frac{L_{sm} p_r p_t [cos2(\theta - \delta) + cos2\delta]}{[1 + p_r p_t cos2(\theta - \delta)]}$$

Multiple Methods Used to Determine $p_r p_t$ in V5

V5 Coefficients Determined Pre-Launch and Not Changed Since

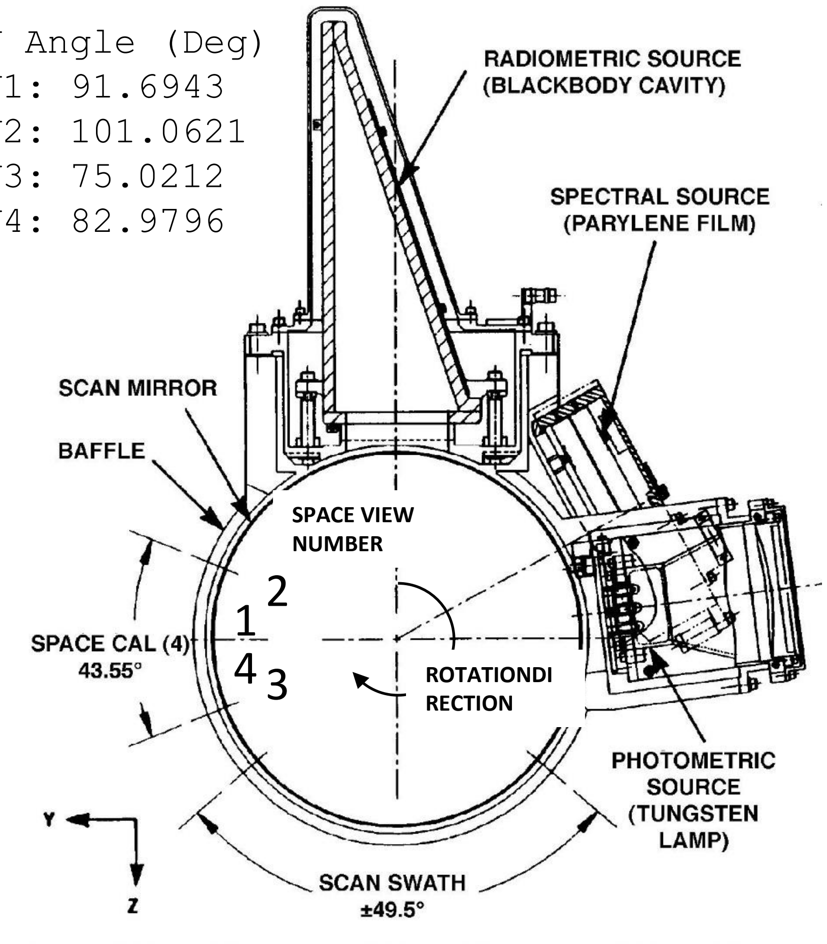


High Uncertainty Especially in LWIR

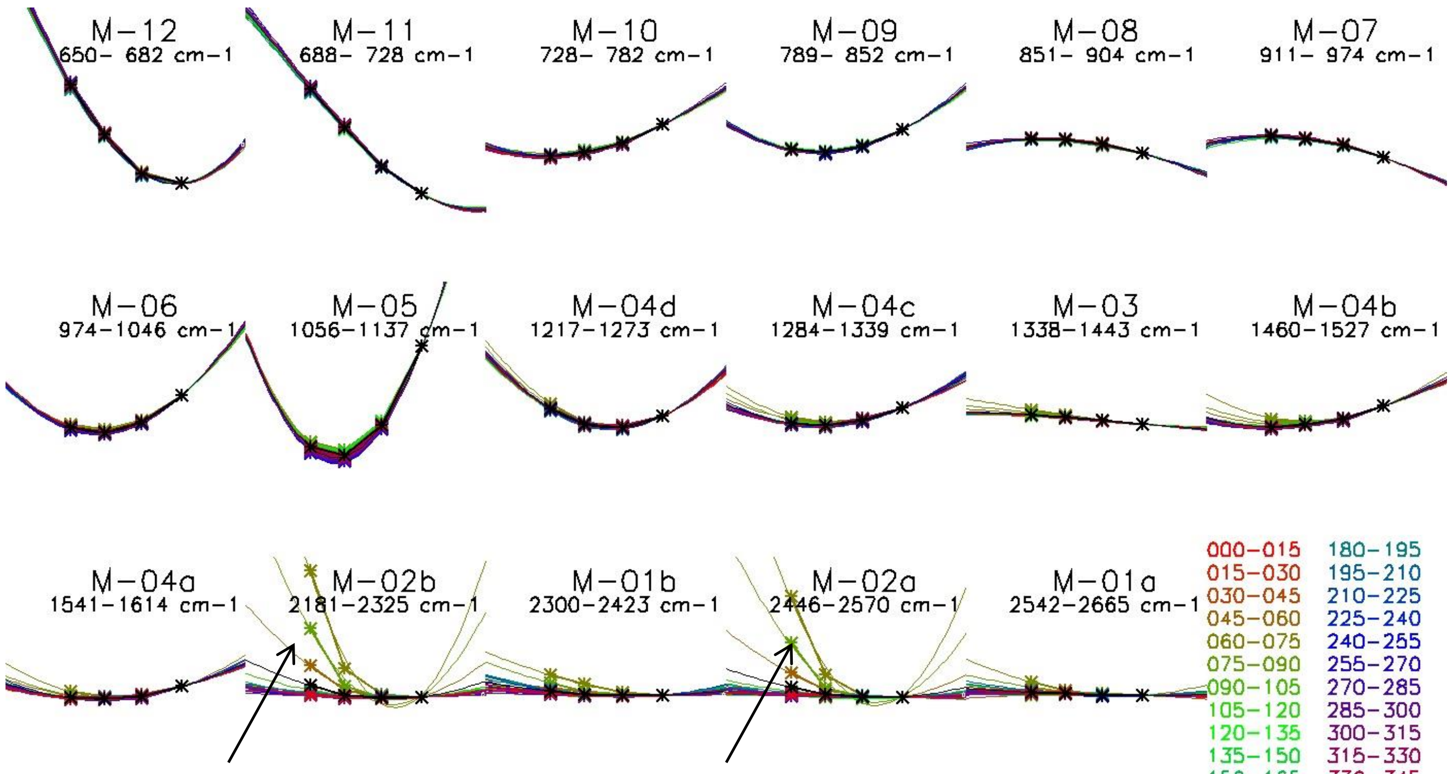
V5 is average of "Measured" and "Modeled" polarization, with Phase = 0

New Method Uses Multiple Space Views to Derive Polarization

SV Angle (Deg)
SV1: 91.6943
SV2: 101.0621
SV3: 75.0212
SV4: 82.9796



Every space view in the mission used to give 171 monthly averages

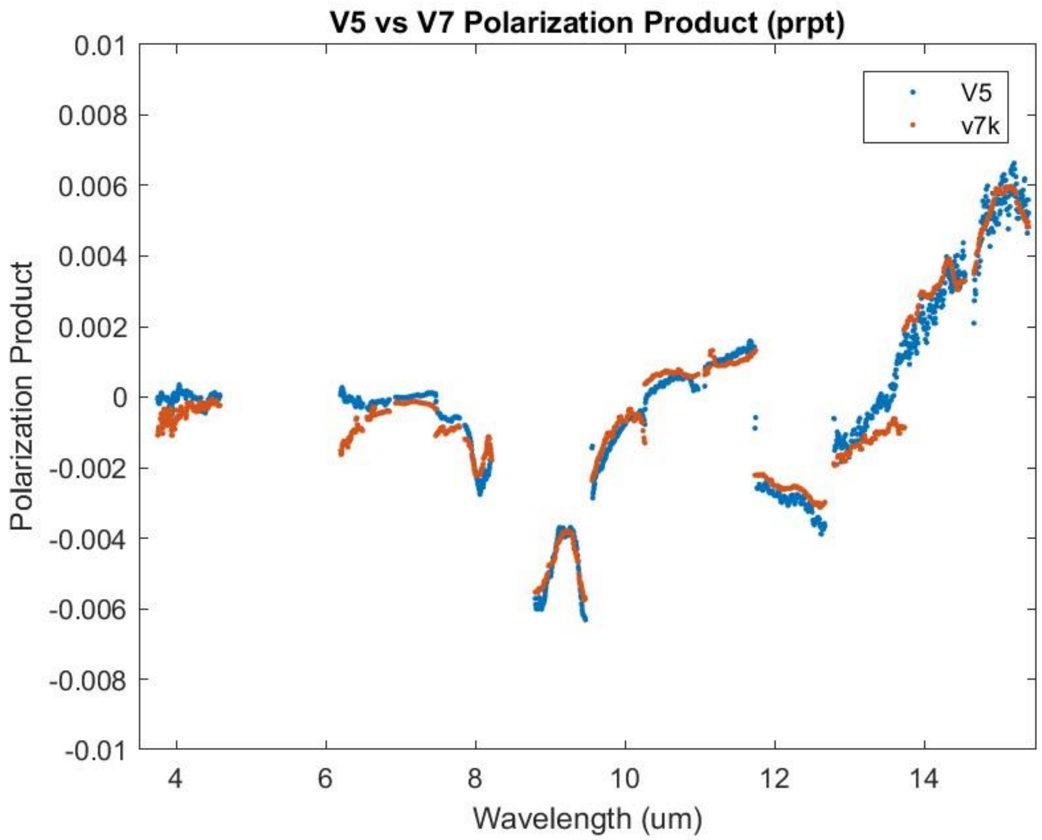


Care taken to omit anomalous readings

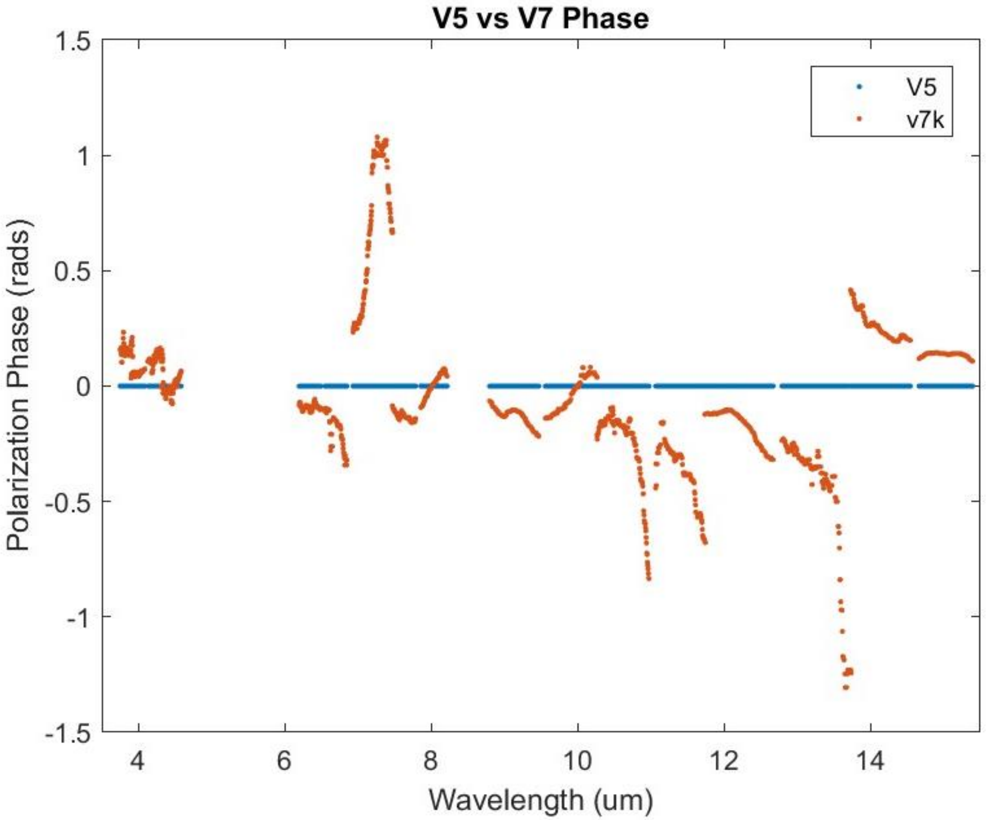
$$(dn_{sv,i} - dn_{sv,1})c_1' = -L_{sm}p_r p_t\left[cos2\theta_{sv,i}cos2\delta + sin2\theta_{sv,i}sin2\delta + cos2\delta\right]$$

V7k Compared to V5: Polarization and Phase

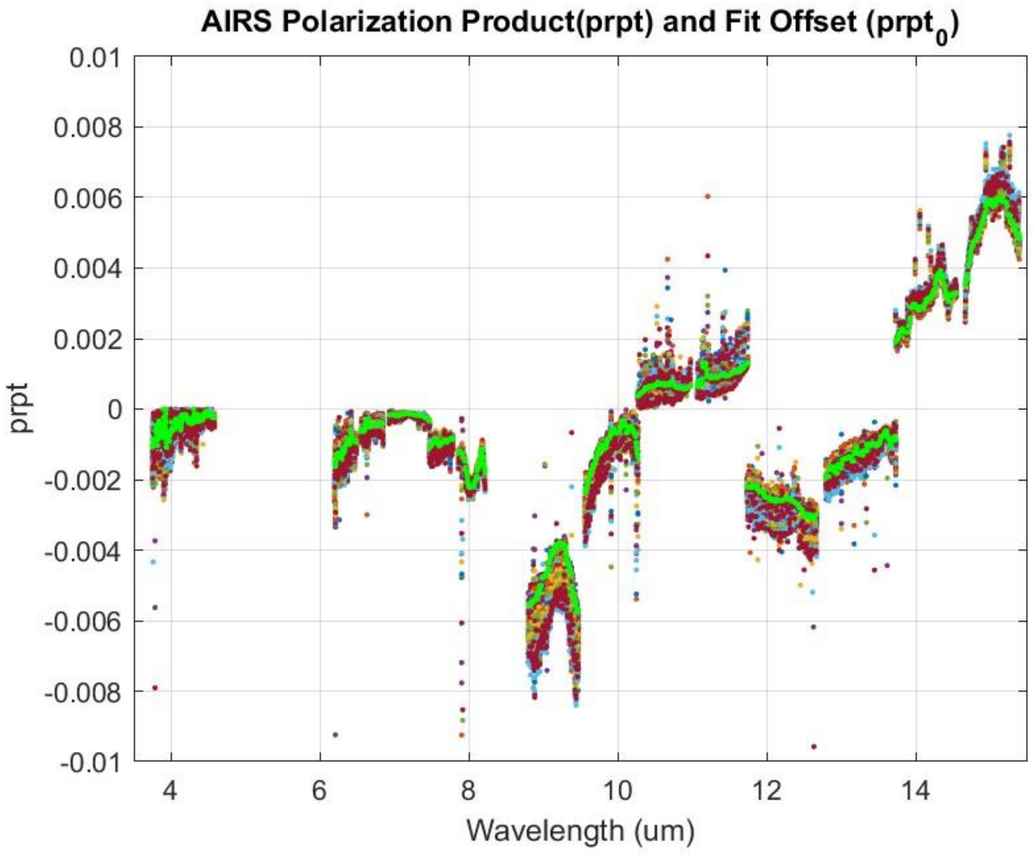
$p_r p_t$

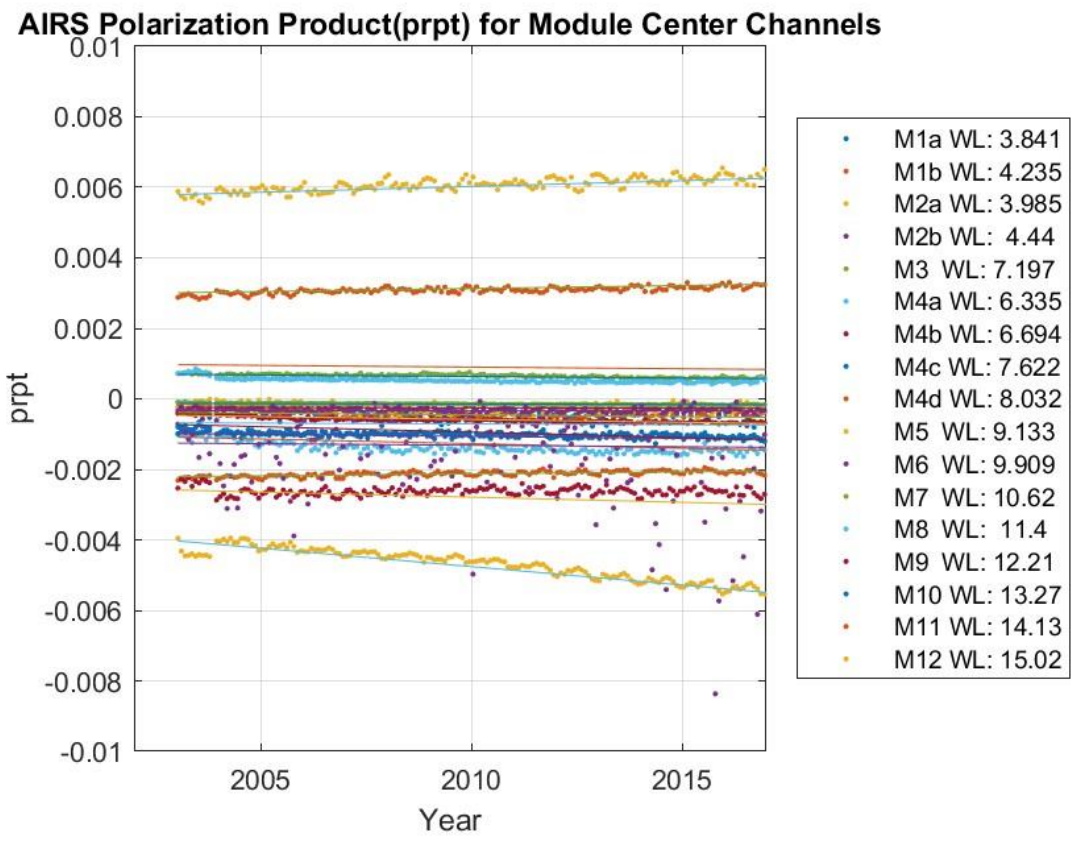


phase



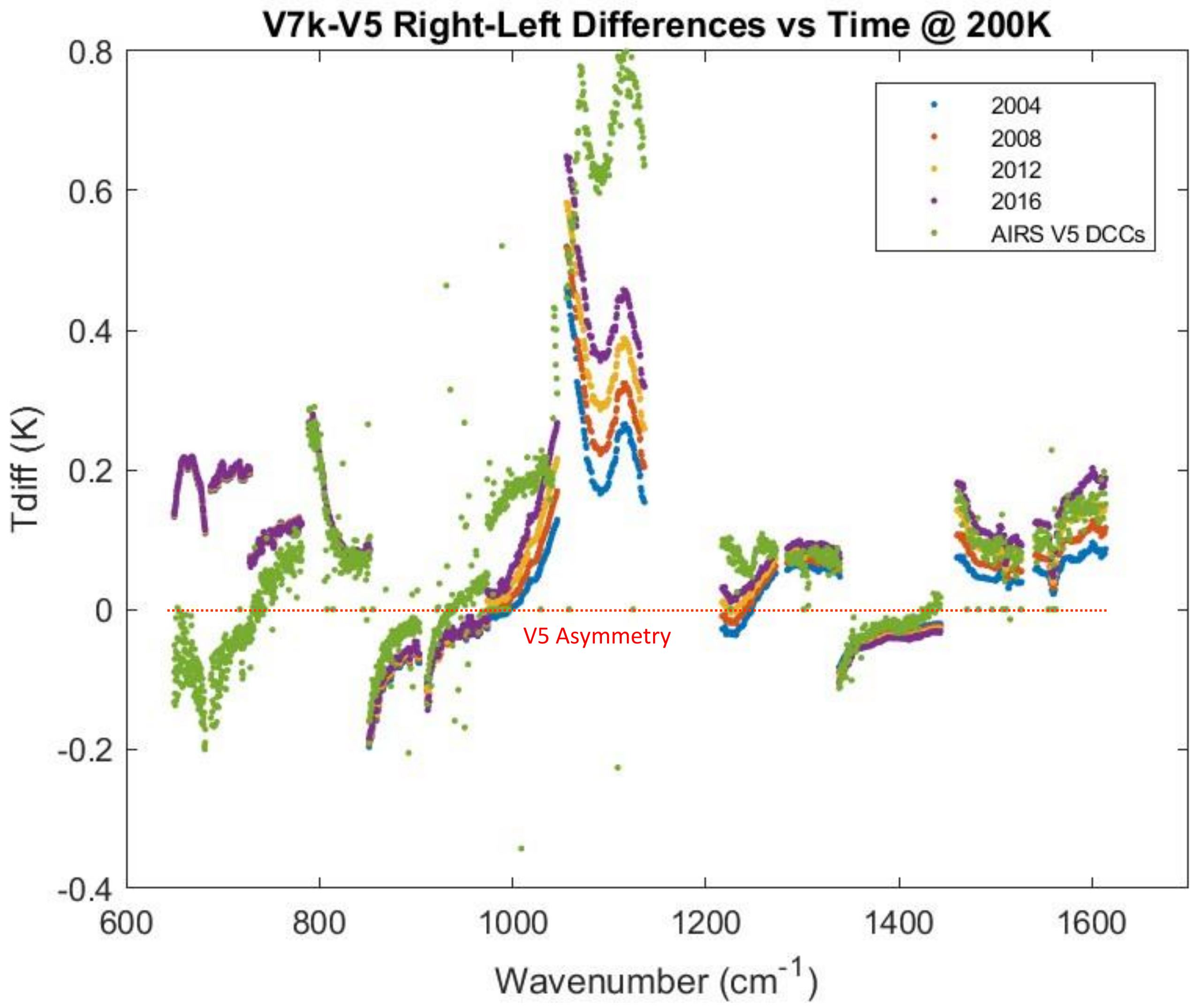
Polarization Parameters Calculated Over Mission Life

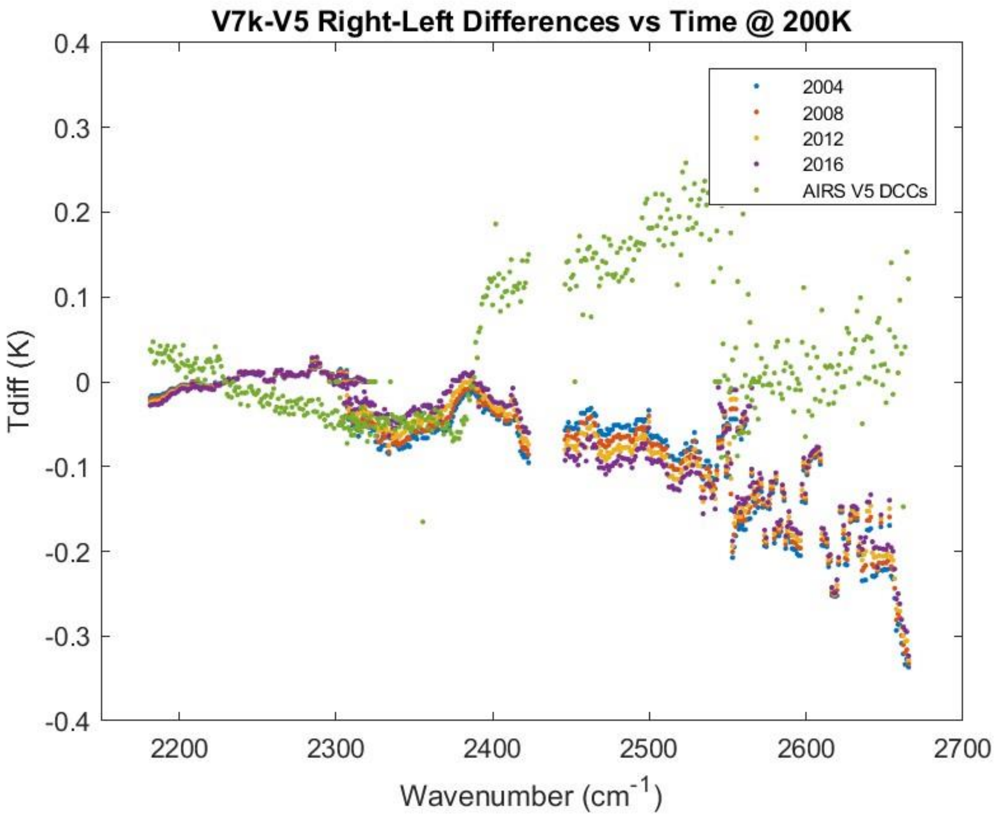




Polarization and Phase in V7k are Time Dependent Using Linear Fit Offset and Slope

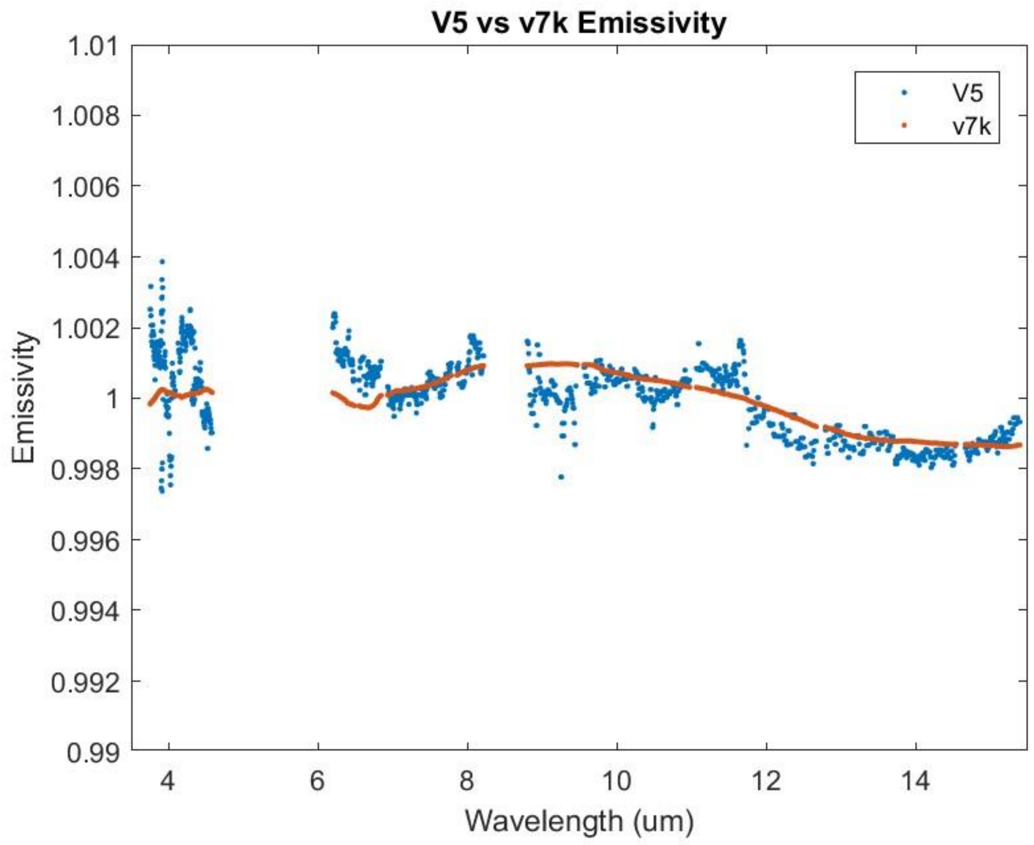
L/R Asymmetries V7k Compared to V5 DCCs



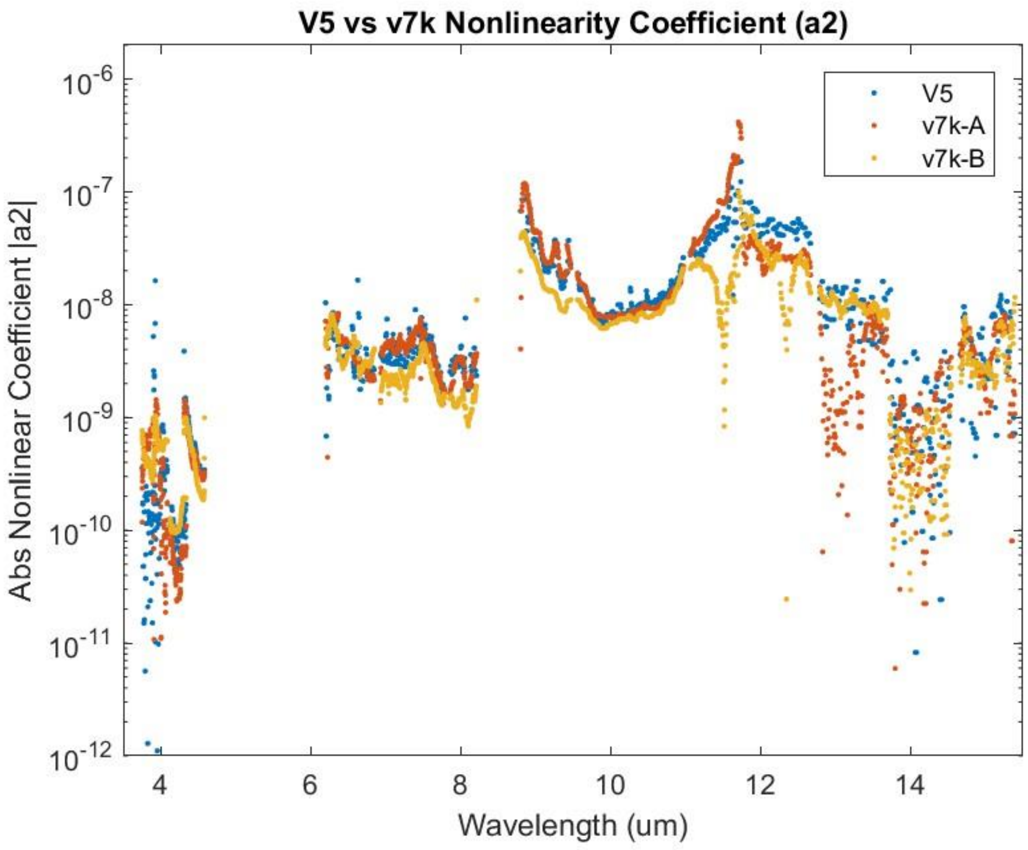


Changes Made to Emissivity and Nonlinearity

V7k Emissivity Smoothed over Channels

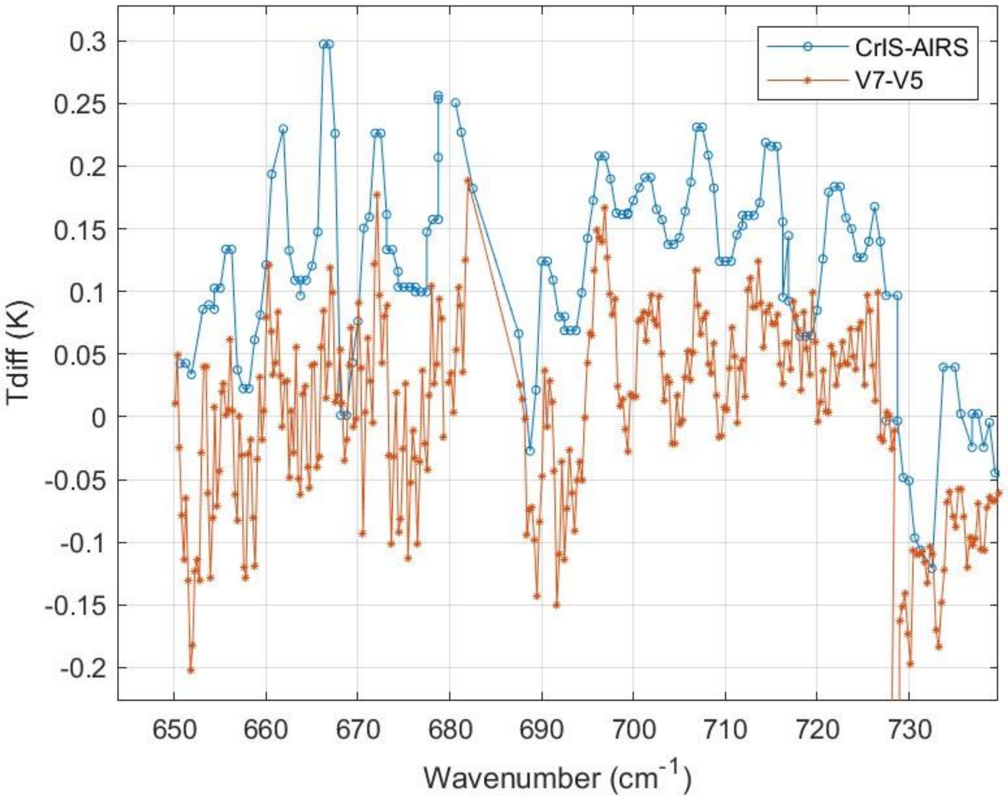


V7k Uses Separate A & B Nonlinearity

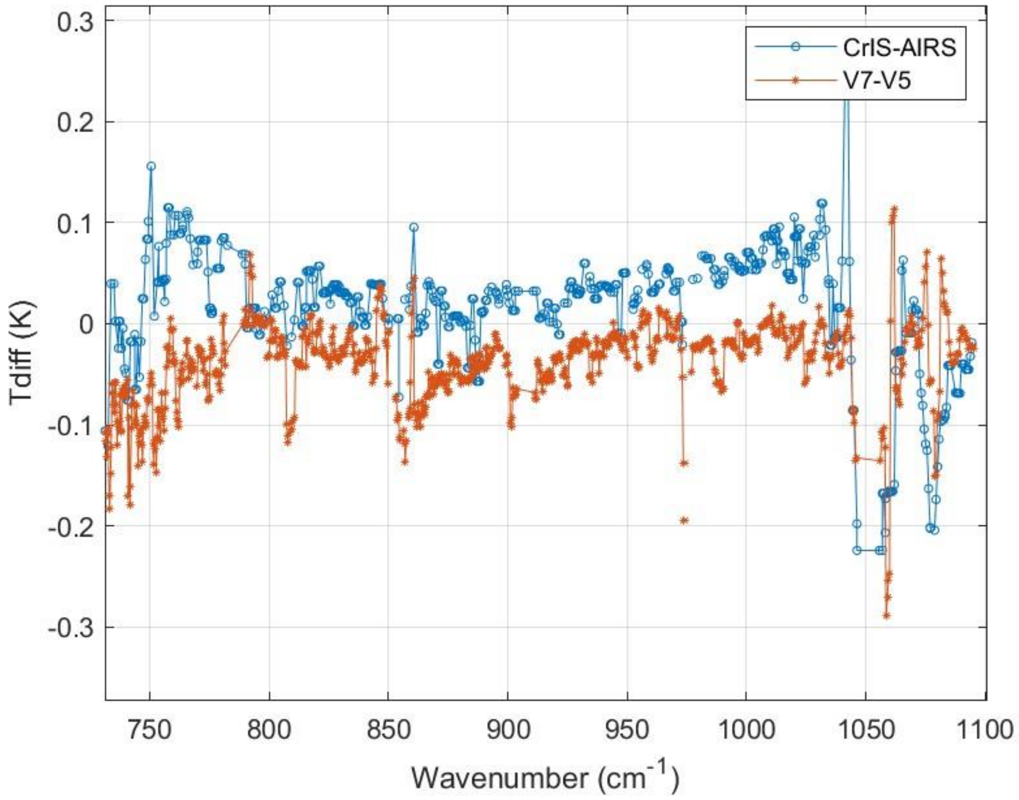


V7k-V5 Differences Follow CrIS-AIRS

VLWIR



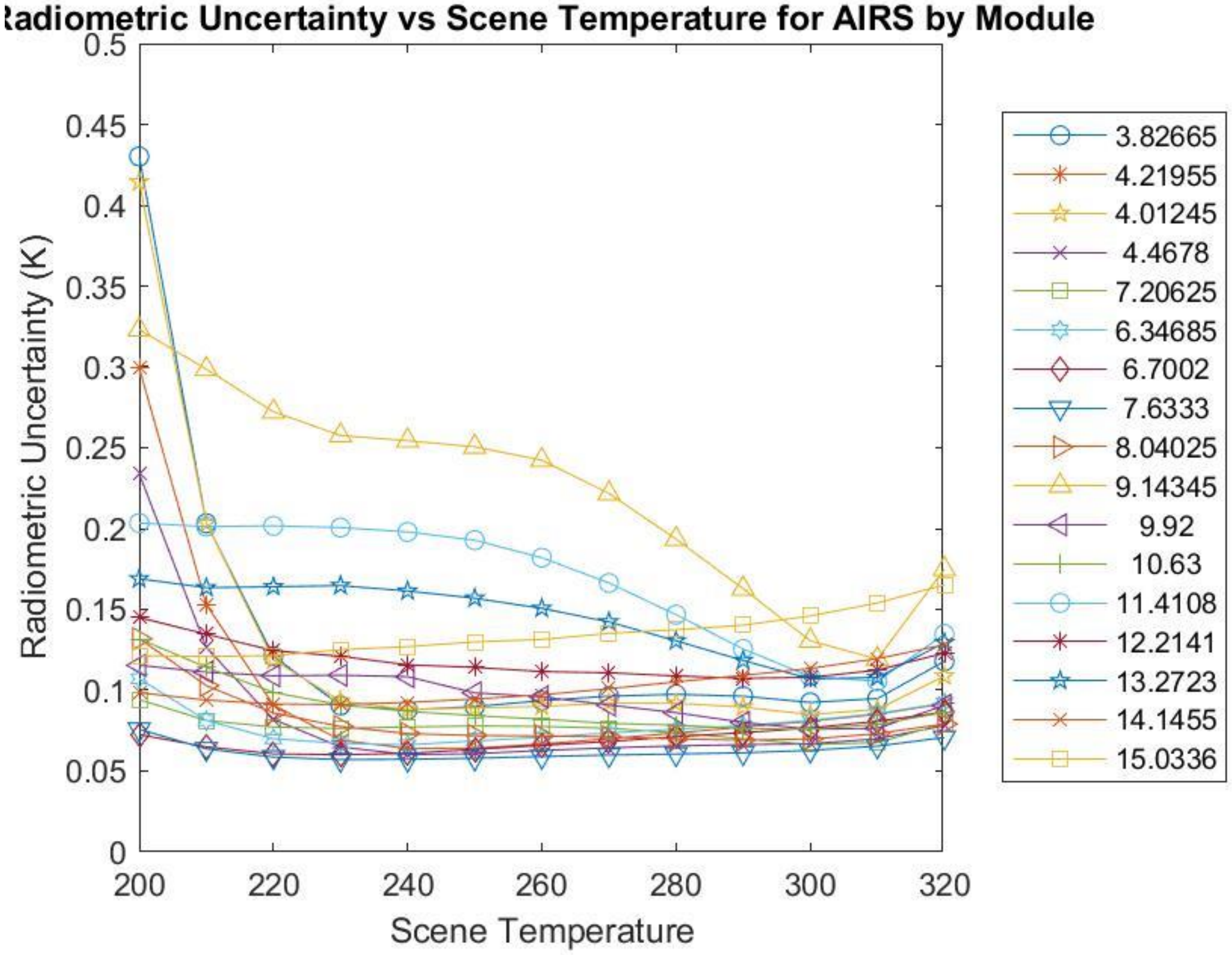
LWIR



V5 Radiometric Uncertainty (1-sigma)

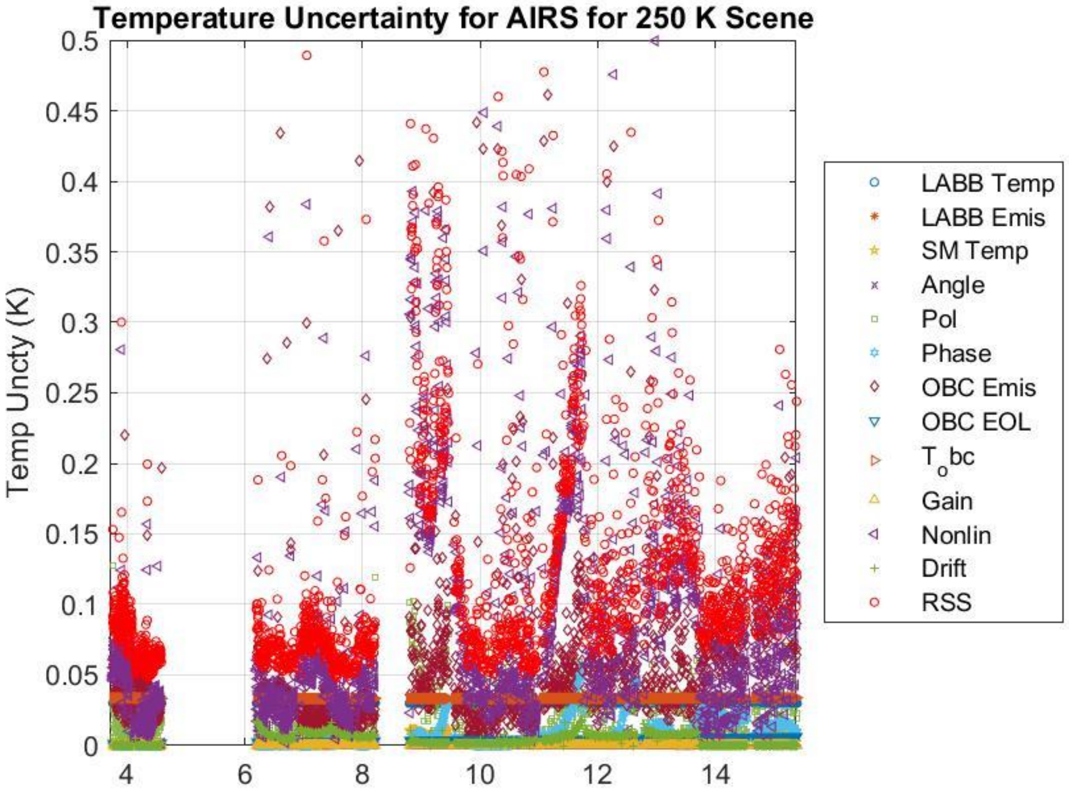
Radiometric Uncertainty Inputs at 9.14 µm
and Impact to Calibration at 260K

Parameter	1-σ Parameter Uncty	1-σ Radiometric Uncty (K)
Version	V5	V5
Uncertainty in LABB Temperature	0.03K	0.03K
Uncertainty in LABB Emissivity	0.00005	0.002K
Uncertainty in Scan Mirror Temperature	1.25K	0.006K
Uncertainty in Polarization Amplitude	.0009	0.04K
Uncertainty in Polarization Phase	.08	0.005K
Uncertainty in OBC Blackbody Emissivity	.002	0.07K
Uncertainty in OBC Blackbody Emissivity (EOL)	0.0001	0.004K
Uncertainty in OBC Blackbody Temperature	0.05K	.04K
Uncertainty in Nonlinearity	2.7%*	0.21K
Uncertainty in drift in space view	0.04dn	0.001K
Total Uncertainty at 260K		0.24K

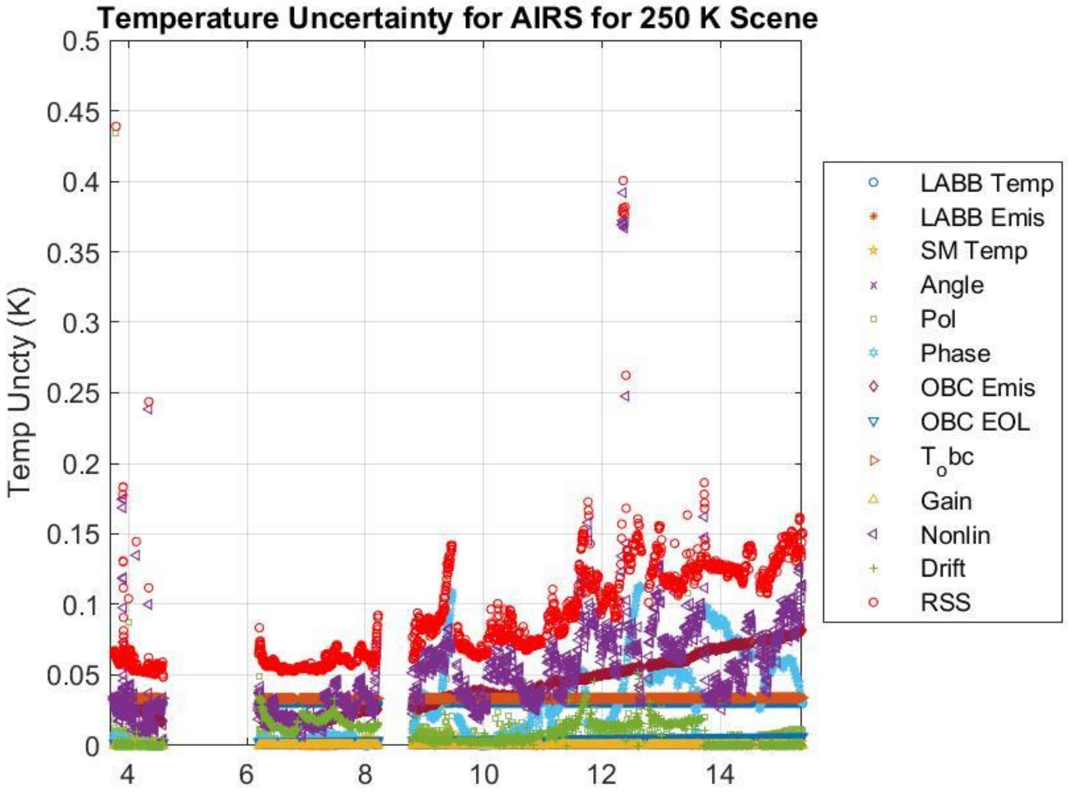


V7k Reduces Radiometric Uncertainty (1σ)

V5



V7k



L1C Designed to Make Life Easier

<u>Version 6.0</u>

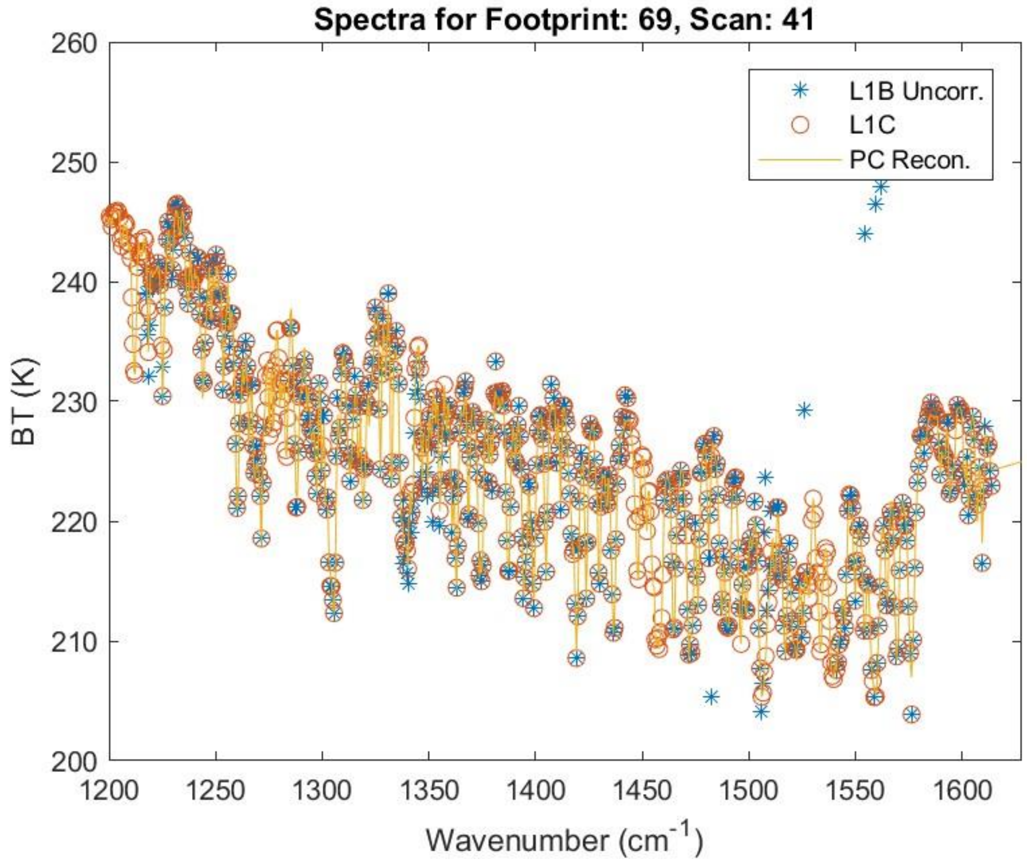
- Designed to facilitate use of AIRS Level 1 radiances
  - For Comparison to other Hyperspectral IR
  - For Comparison to Broadband Imagers
  - For Ingest by L2 Retrievals
- Version 5 L1B for all “good” channels
- Fills Dead Channels with PC Reconstruction (PCR)
- Fills bad Cij (Co-registration) Pixels with PCR
- Fills Gap with PCR
- Fills Very High Noise Pixels with PCR
- V6.0 L1C is available only on a limited basis

<u>Version 6.6</u>

- Same as Version 6.0 but with…
- Constant Frequency Grid (does not change with time)
- V6.6 L1C will be used to support LLS’s CHIRP product

<u>Version 7.0</u>

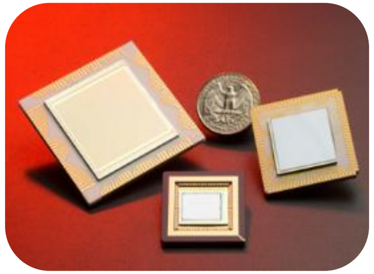
- Same as Version 6.6 but with
- Updated filling algorithms.
- Version 7k Radiometric and Polarization Coefficients
- netCDF Output



AIRS.2014.03.01.124.L1C.AIRS_Rad.v6.1.0.2.X14295151145.hdf

CubeSat IR Atmospheric Sounder (CIRAS) at JPL

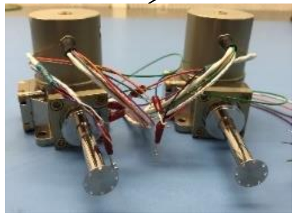
FPA
HOTBIRD
(JPL)

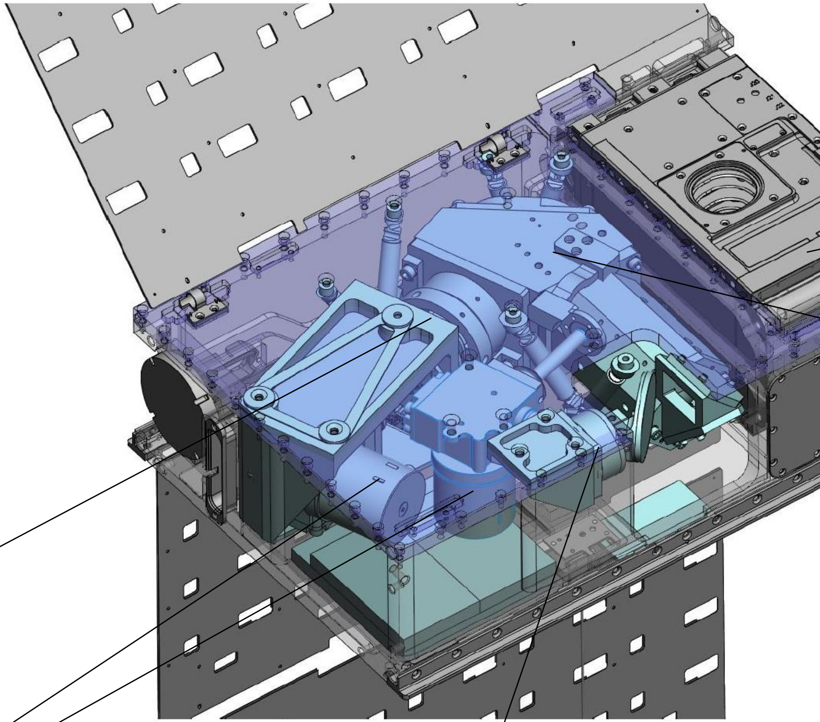


Camera Electronics
(IR Cameras)

Dewar (IDCA)
(IR Cameras)

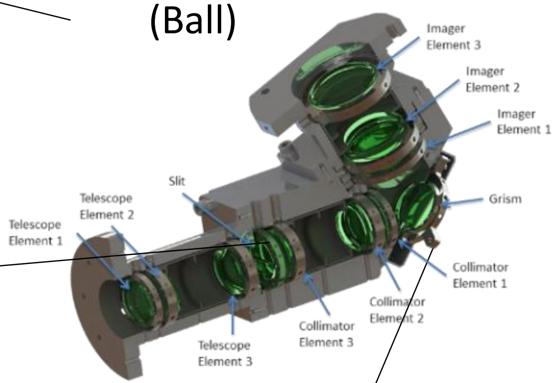
Cryocoolers +
Electronics
(Ricor K508N)





Spacecraft
(BCT)

Optics Assembly
(Ball)

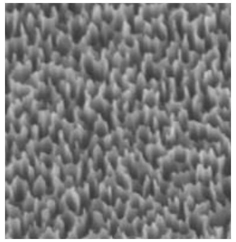


Slit (JPL)

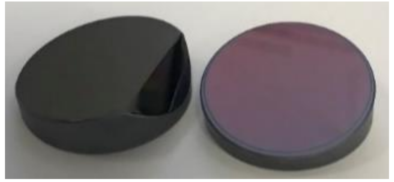
Payload
Electronics

Stepper Motor +
Mirror
(Lin Eng)

Blackbody
Assembly
Black Silicon



Immersion Grating
(JPL)



Hardware Available

Designs Available

Summary and Conclusions

- AIRS on Aqua Healthy. Expect mission to continue beyond 2022.
- Continuity from operational weather sounders: CrIS and IASI
- AIRS designed and tested to produce SI traceable radiances
- Radiometric Calibration Coefficients Updated
    - Current operational version using pre-launch coefficients (V5)
    - Updates provided to polarization, emissivity, nonlinearity (V7k)
- V7k Improvements seen in:
    - Reduced Bias and L/R Assymetry in Cold Scenes
    - Agrees better with CrIS
    - Reduction in Radiometric Accuracy
- AIRS Level 1C Fills Bad Channels and Gaps in Spectra. Easier than L1B
- New Technologies enable IR sounding in CubeSat with full aperture cal